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12

BEHAVIOR OF FUELS AT LOW TEMPERATURES

INTERIM REPORT
AFLRL No. 138

by

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In developing the filter/separator component of the Arctic Fuel Dispensing Equipment, MERADCOM is considering two options: (1) development of a completely new filter/separator or (2) modification of the current Military Standard filter/separator for use at low temperatures. This report contains test data on the low-temperature behavior of five test fuels - JP-4, JP-5, JP-8, DF-A, and DF-1 as well as two additional test fuels made by adding icing inhibitor (ethylene glycol monomethyl ether) to the DF-A and DF-1.

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20. ABSTRACT (Cont'd)

Four additional fuels were obtained from Alaska (JP-4, Jet A-1, DF-A, and JP-5) and low temperature behavior of these field samples was determined. This report contains (1) a brief summary of industry practice in handling fuels at low temperatures, (2) inspection properties of test fuels, (3) viscosities and conductivities of fuels at low temperatures, (4) fuel contaminant behavior at low temperatures, and (5) fuel system icing inhibitor effects at low temperatures.

FOREWORD

The work reported herein was conducted at the U.S. Army Fuels and Lubricants Research Laboratory (USAFLRL), located at Southwest Research Institute, San Antonio, Texas under contract No. DAAK70-80-C-0001. The Contract Officer's representative was Mr. F.W. Schaekel, DRDME-GL, of USAMERADCOM. Mr. William R. Williams of the same office was project technical monitor.

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I. INTRODUCTION

The Fuels and Lubricants Division, Energy and Water Resources Laboratory, MERADCOM, is responsible for the development of the filter/separator component of the Arctic Fuel Dispensing Equipment (AFDE). The AFDE must be capable of operation at -51°C (-60°F). Figure 1 shows an artist's conception of an arctic forward refueling area using the AFDE. MERADCOM is considering the following two options for the AFDE: (1) development of a completely new filter/separator or (2) modification of the current Military Standard filter/separators for use at low temperatures. This report contains data on the low-temperature behavior of several fuels and will serve as an aid to MERADCOM in developing the filter/separator portion of the AFDE.

II. BRIEF SUMMARY OF INDUSTRY PRACTICE

A brief survey was made to determine industry practice with respect to cold weather fuel handling and filtration practices in arctic climates. As expected, fuels intended for use in turbine engine aircraft are kept clean and dry and are usually run through a filter/separator each time the fuel is moved from one location to another. Diesel fuels are not subjected to extensive filtering or coalescer treatment. The Alaska Railroad (Anchorage, AK) reported no special filtration of diesel fuel. The Alaska Department of Highway (Fairbanks, AK) also reported no additional diesel fuel filtration after receiving the fuel from the supplier. Alyeska Pipeline Service Company reported a final fuel filtration prior to fueling gas turbines which drive the pipeline. However, the fuel filters are located in a heated building and not subjected to arctic conditions. The fuel is generally quite clean and dry as filter elements are infrequently changed. In other Alyeska locations, fuel is heated either by tank heaters or by the addition of warm product from topping units. In either case, fuel temperature is kept above 0°C to avoid possible filter plugging due to ice crystals.

U.S. Army Photograph

FIGURE 1. ARCTIC FUELS DISPENSING EQUIPMENT
(Arctic Forward Area Refueling Equipment)

III. LOW-TEMPERATURE FUEL INVESTIGATIONS

A. Test Fuels

Five test fuels were obtained by the U.S. Army Fuels and Lubricants Research Laboratory (AFLRL) and analyzed for properties required by their respective specifications. The fuels were JP-4, JP-5, JP-8, DF-A, and DF-1 (1-3)*. The test fuel properties are shown in Table 1. The five test fuels met their respective specifications with the following exceptions: JP-5 had slightly higher TAN than allowed, JP-8 had a slightly higher freeze point than permitted by specification, and the JP-4 apparently did not contain the electrical conductivity additive as required by MIL-T-5624L. Two additional test fuels were made by adding 0.15 vol% ethylene glycol monomethyl ether (EGME) to the DF-A and DF-1 (4). The JP-4, JP-5, and JP-8 all contained from 0.08 to 0.11 vol% EGME. MERADCOM supplied the following four fuels from Alaska: JP-4, JP-5, Jet A-1 (5) and DF-A. The analyses of the Alaskan fuels are shown in Table 2. It is of interest to note the rather high fuel system icing inhibitor (FSII) content of the Alaskan DF-A (0.28 vol%). The Alaskan Jet A-1 contained 0.02 vol% EGME while the Alaskan JP-4 had 0.07 vol% EGME and the JP-5 contained 0.09 vol% EGME. These fuels were included in portions of the low-temperature fuel behavior determinations.

B. Fuel Viscosity and Conductivity

Fuel viscosity and conductivity determinations were made for the seven non-Alaskan test fuels at 10°F intervals from +30°F (-1.1°C) to -60°F (-51.1°C). Because cooling rate has a direct effect on crystal size, the test fuels were all cooled at a constant rate (6). The results are shown in Tables 3 through 9. Each fuel was tested with water present at three different levels, including a water-"saturated" sample. The fuels apparently become water saturated at around 200 to 400 ppm water, as vigorous mixing with water failed to increase the water content of the fuels. The JP-4 and JP-5 fuels were vigorously stirred with added water, while the remaining fuels were subjected to sonic treatment as a means of dissolving and dispersing water in them. Water

*Underscored numbers in parentheses refer to the list of references at the end of this report.

TABLE 1. TEST FUELS PROPERTIES

Property	Test Method	AL-9254 JP-4	AL-7247 JP-5	AL-9293 JP-8	AL-9294 DF-1	AL-9295 DFA
Gravity, °API	D 287	56.4	40.3	47.9	42.2	47.7
Flash Point, °C	D 93	ND	60	43	82	45
Cloud Point, °C	D 2500	ND	-46	-55	-23	-52
Pour Point, °C	D 97	ND	-57	-65	-36	-56
Freeze Point, °C	D 2386	-65	-46	-44	-18	-52
Kin Vis at 40°C, cSt	D 445	ND	1.58	1.08	1.93	1.18
Kin Vis at -20°C, cSt	D 445	ND	6.26	3.06	ND	ND
Distillation, °C	D 86					
10%		90	199	172	219	178
20%		101	205	173	221	182
50%		136	218	179	229	191
90%		194	246	204	278	214
EP		238	266	260	325	252
Residue, vol%		1.5	1.0	1.0	1.0	1.0
Heat of Combustion, MJ/kg	D 240					
Gross		46.94	46.58	46.43	46.42	46.08
Net		43.87	43.69	43.43	43.47	43.09
Copper Corrosion at 100°C	D 130	ND	1a	1a	1a	1a
RVP, kPa	D 323	19.99	ND	ND	ND	ND
Total Acid No., mg KOH/g	D 664	0.01	0.20	0.01	ND	ND
FIA, vol%	D 1319					
Aromatics		9	20	13	14	11
Olefins		1	2	1	2	2
Saturates		90	78	86	84	87
Sulfur, wt%	D 2622	0.11	0.16	0.01	0.02	0.01
Particulate Matter, mg/l	D 2276	0.3	0.6	0.5	0.4	0.5
Existent Gum, mg/100 ml	D 381	1.7	1.3	0.5	ND	ND
Carbon, wt%	a	85.26	86.30	85.73	86.03	85.10
Hydrogen, wt%	a	14.46	13.59	14.15	13.88	14.08
Water, ppm	D 1744	70	30	30	30	80
FSII, vol%	FTMS 791	0.10	0.11	0.08	0.00	0.00
Cetane No.	D 613	ND	ND	ND	60	51

ND = Not determined.
a = AFLRL microcombustion method.

TABLE 2. ALASKAN FUELS PROPERTIES

Code Description		AL-9476 JP-4	AL-9477 Jet A-1	AL-9478 DFA	AL-9479 JP-5
Property	Test Method				
Gravity, °API	D 287	53.3	42.2	40.8	41.4
Flash Point, °C	D 93	ND	41	43	63
Cloud Point, °C	D 2500	Below -65	-52	-43	-52
Pour Point, °C	D 97	Below -65	-58	-53	-60
Freeze Point, °C	D 2386	Below -65	-49	-47	-56
Kin Vis at 40°C, cSt	D 445	ND	1.23	1.44	1.47
Kin Vis at -20°C, cSt	D 445	1.38	3.89	5.12	5.40
Distillation, °C	D 86				
10%		101	168	187	202
20%		106	175	197	205
50%		118	203	215	213
90%		178	246	245	236
EP		241	272	274	268
Residue, vol%		1.0	1.0	1.0	1.0
Heat of Combustion, MJ/kg	D 240				
Gross		45.82	45.11	45.42	45.71
Net		42.35	42.26	42.58	42.86
Copper Corrosion at 100°C	D 130	ND	1a	1a	1a
RVP, kPa	D 323	13.1	ND	ND	ND
Total Acid No., mg KOH/g	D 664	0.001	0.002	0.001	0.000
FIA, vol%	D 1319				
Aromatics		15.2	22.5	17.6	19.9
Olefins		1.3	1.9	2.4	2.7
Saturates		83.5	75.6	80.0	77.4
Sulfur, wt%	D 2622	0.02	0.09	0.02	0.01
Particulate Matter, mg/l	D 2276	0.5	0.4	0.7	0.5
Existent Gum, mg/100 ml	D 381	0.6	0.4	1.0	0.7
Carbon, wt%	a	85.98	86.16	85.93	85.49
Hydrogen, wt%	a	14.01	13.42	13.52	13.42
Water, ppm	D 1744	100	110	90	40
FSII, vol%	FTMS 791	0.07	0.02	0.28	0.09
Cetane No.	D 613	28	40	44	41

ND = Not Determined.
a = AFLRL Microcombustion method.

content of the fuels was determined after the stirring or sonic treatment by ASTM D 1744. The conductivity measurements were made using a portable conductivity meter which met the requirements of ASTM test method D 2624. As shown in Figure 2, the temperature/viscosity determinations were linear for the as received fuels when plotted on an ASTM temperature-viscosity chart. As shown in Tables 3 through 9, temperature/viscosity determinations apparently were not influenced by fuel/water content. The conductivity measurements at varying low temperatures were generally constant (±2 conductivity units) per fuel. The addition of 0.15 vol% EGME to DF-1 and DFA did not effect low-temperature viscosities or conductivities.

Fuel viscosity and conductivity determinations were made for the four Alaskan fuels at 10°F intervals from +10°F (-12.2°C) to -60°F (-51.1°C). The results are shown in Table 10. Sample AL-9476 (JP-4) showed a greatly reduced absolute conductivity (-56 CU) at the very low test temperatures. This trend was also observed with the Jet A-1 and DF-A samples, but to a lesser absolute extent, because of the much lower initial conductivities.

C. Fuel System Icing Inhibitor (FSII) Effects at Low Temperatures

FSII/water addition effects were determined at low temperatures. Water was added in 0.01 vol% increments to test fuels JP-4, DF-A, DF-A + 0.15 vol% FSII and Alaskan fuels JP-4, JP-5, and DF-A. The tests were performed at 10°F intervals from +10°F (-12.2°C) to -60°F (-51.1°C). The results indicated that ice forms for each fuel at each temperature with the first 0.01 vol% addition of water. The quantity of crystals observed was insufficient to allow a measurement of FSII content to determine if the icing inhibitor was picked up by the added water. Thus, an additional experiment was run to determine the amount of FSII that is removed at each temperature (+10° to -60°F), ΔT = 10°F) by the addition and swirling of 0.15 vol% water. The results, shown in Table 11, are expressed as FSII content remaining after low-temperature water exposure. All of the fuels retained most if not all of the FSII after this low-temperature exposure to water.

TABLE 3. FUEL VISCOSITY AND CONDUCTIVITY FOR JP-4

Fuel: JP-4, AL-9254
0.10 vol% EGME

Sample Description	"As Recv'd"		Added Water		Added Water	
Water Content, D 1744, ppm	70		120		400	
Test °C(°F)	Kin Vis, cSt	CU*	Kin Vis, cSt	CU*	Kin Vis, cSt	CU*
-1.1(30)	1.13	3	1.12	4	1.12	5
-6.7(20)	1.21	6	1.22	4	1.22	4
-12.2(10)	1.32	4	1.33	4	1.33	4
-17.8(0)	1.46	5	1.46	3	1.44	3
-23.3(-10)	1.61	4	1.59	4	1.60	3
-28.9(-20)	1.79	4	1.80	4	1.77	4
-34.4(-30)	1.98	4	1.99	4	2.00	5
-40(-40)	2.26	4	2.29	5	2.29	5
-45.6(-50)	2.56	3	2.61	5	2.61	5
-51.1(-60)	2.96	5	3.01	5	3.01	5

* CU = Conductivity Units = picosiemens/meter by ASTM Method D 2624.

TABLE 4. FUEL VISCOSITY AND CONDUCTIVITY FOR JP-5

Fuel: JP-5, AL-7247
0.11 vol% EGME

Sample Description	"As Recv'd"		Added Water		Added Water	
Water Content, D 1744, ppm	30		60		220	
Test °C(°F)	Kin Vis, cSt	CU*	Kin Vis, cSt	CU*	Kin Vis, cSt	CU*
-1.1(30)	3.54	3	3.55	4	3.55	1
-6.7(20)	4.08	5	4.13	4	4.13	2
-12.2(10)	4.79	4	4.81	6	4.83	4
-17.8(0)	5.72	3	5.76	3	5.68	2
-23.3(-10)	6.93	2	7.00	3	6.88	2
-28.9(-20)	8.58	3	8.67	4	8.59	4
-34.4(-30)	10.73	3	10.82	4	10.86	4
-40(-40)	14.14	3	14.17	3	14.13	3
-45.6(-50)	19.33	3	19.18	3	19.16	3
-51.1(-60)	**	2	**	3	**	3

* CU = Conductivity Units = picosiemens/meter by ASTM Method D 2624.
** Crystals restricted flow in viscosity tube; however, conductivity could still be determined.

TABLE 5. FUEL VISCOSITY AND CONDUCTIVITY FOR DF-1

Fuel: DF-1, AL-9294

Sample Description	"As Recv'd"		Added Water		Added Water	
Water Content, D 1744, ppm	30		180		200	
Test °C(°F)	Kin Vis, cSt	CU*	Kin Vis, cSt	CU*	Kin Vis, cSt	CU*
-1.1(30)	4.69	3	4.75	2	4.72	2
-6.7(20)	5.54	3	5.52	2	5.58	1
-12.2(10)	6.62	2	6.64	2	6.62	2
-17.8(0)	8.07**	2	8.15	2	8.09	1
-23.3(-10)	***	2	10.55**	2	10.19**	1
-28.9(-20)	ND	ND	***	2	***	1

* CU = Conductivity Units = picosiemens/meter by ASTM Method D 2624.
** Crystals settling out.
*** Crystals restricted flow in viscosity tube; however, conductivity could still be determined.
ND Not determined.

TABLE 6. FUEL VISCOSITY AND CONDUCTIVITY FOR DF-1 + FSII

Fuel: DF-1 + FSII
AL-9294 + 0.15 vol% EGME

Sample Description	"As Recv'd"		Added Water		Added Water	
FSII, vol%	0.14		0.18		0.18	
Water Content, D 1744, ppm	30		50		190	
Test °C(°F)	Kin Vis, cSt	CU*	Kin Vis, cSt	CU*	Kin Vis, cSt	CU*
-1.1(30)	4.71	1	4.69	2	4.69	2
-6.7(20)	5.54	2	5.53	2	5.53	2
-12.2(10)	6.61	2	6.59	2	6.62	1
-17.8(0)	8.08	2	8.07	1	8.10	1
-23.3(-10)	**	2	10.20***	1	10.24***	2
-28.9(-20)	ND	ND	15.92***	1	**	2
-34.4(-30)	ND	ND	**	1	ND	ND

* CU = Conductivity Units = picosiemens/meter by ASTM Method D 2624.
** Crystals restricted flow in viscosity tube; however, conductivity could still be determined.
*** Crystals settling out
ND Not determined.

TABLE 7. FUEL VISCOSITY AND CONDUCTIVITY FOR DF-A

Fuel: DF-A, AL-9295

Sample Description	"As Recv'd"		Added Water		Added Water	
Water Content, D 1744, ppm	80		120		290	
Test °C(°F)	Kin Vis, cSt	CU*	Kin Vis, cSt	CU*	Kin Vis, cSt	CU*
-1.1(30)	2.32	2	2.33	2	2.32	1
-6.7(20)	2.61	2	2.63	2	2.62	2
-12.2(10)	2.95	2	2.97	2	2.96	2
-17.8(0)	3.39	2	3.44	2	3.42	1
-23.3(-10)	3.97	2	4.02	2	4.00	1
-28.9(-20)	4.77	2	4.82	2	4.82	2
-34.4(-30)	5.82	2	5.68	2	5.85	2
-40(-40)	6.87	2	6.96	2	7.12	2
-45.6(-50)	8.61	2	8.71	2	8.89	2
-51.1(-60)	11.10	1	11.19	1	11.13	1

* CU = Conductivity Units = picosiemens/meter by ASTM Method D 2624.

TABLE 8. FUEL VISCOSITY AND CONDUCTIVITY FOR DF-A + FSII

Fuel: DF-A + FSII
AL-9295 + 0.15 vol% EGME

Sample Description	"As Recv'd"		Added Water		Added Water	
FSII, vol%	0.14		0.18		0.18	
Water Content, D 1744, ppm	60		140		260	
Test °C(°F)	Kin Vis, cSt	CU*	Kin Vis, cSt	CU*	Kin Vis, cSt	CU*
-1.1(30)	2.31	2	2.29	1	2.31	1
-6.7(20)	2.59	2	2.59	1	2.61	1
-12.2(10)	2.93	2	2.94	0	2.94	0
-17.8(0)	3.38	1	3.40	0	3.39	0
-23.3(-10)	3.96	2	3.98	2	3.97	2
-28.9(-20)	4.20	2	4.76	1	4.75	2
-34.4(-30)	5.58	3	5.58	1	5.58	1
-40(-40)	6.89	3	6.85	1	6.84	1
-45.6(-50)	8.65	2	8.56	2	8.57	2
-51.1(-60)	11.10	2	11.08	2	11.14	3

* CU = Conductivity Units = picosiemens/meter by ASTM Method 2624.

TABLE 9. FUEL VISCOSITY AND CONDUCTIVITY FOR JP-8

Fuel: JP-8, AL-9293
0.08 vol% EGME

Sample Description	"As Recv'd"		Added Water		Added Water	
Water Content, D 1744, ppm	20		140		200	
Test °C(°F)	Kin Vis, cSt	CU*	Kin Vis, cSt	CU*	Kin Vis, cSt	CU*
-1.1(30)	2.06	4	2.05	6	2.06	5
-6.7(20)	2.30	6	2.29	5	2.30	5
-12.2(10)	2.59	6	2.58	5	2.59	4
-17.8(0)	2.99	6	2.94	4	2.95	4
-23.3(-10)	3.42	6	3.42	3	3.44	4
-28.9(-20)	4.04	8	4.09	3	4.09	4
-34.4(-30)	4.73	8	4.91	3	4.93	4
-40(-40)	5.71	7	5.69	3	5.70	4
-45.6(-50)	7.06	6	7.07	2	7.07	2
-51.1(-60)	8.99	8	8.93	2	8.95	2

* CU = Conductivity Units = picosiemens/meter by ASTM Method D 2624.

TABLE 10. FUEL VISCOSITY AND CONDUCTIVITY FOR ALASKAN FUELS

Fuel	AL-9476		AL-9477		AL-9478		AL-9479	
Sample Description	JP-4		Jet A-1		DFA		JP-5	
FSII Content, vol%	0.07		0.02		0.28		0.09	
Water Content, D 1744, ppm	100		110		90		40	
Test °C(°F)	Kin Vis, cSt	CU*	Kin Vis, cSt	CU*	Kin Vis, cSt	CU*	Kin Vis, cSt	CU*
-12.2(10)	1.25	60	3.25	4	4.10	8	4.37	1
-17.8(0)	1.37	60	3.74	4	4.80	8	5.14	1
-23.3(-10)	1.51	70	4.44	4	5.80	8	6.24	1
-28.9(-20)	1.67	70	5.35	4	7.03	10	7.66	2
-34.4(-30)	1.86	70	6.40	3	8.71	10	9.53	2
-40(-40)	2.08	30	7.92	0	11.06	6	12.28	2
-45.6(-50)	2.36	20	10.03**	0	14.53	5	16.42	1
-51.1(-60)	2.70	14	-Solid-	-	- Solid -		22.71	0

* CU = Conductivity Units = picosiemens/meter by ASTM Method D 2624.
** Crystals present

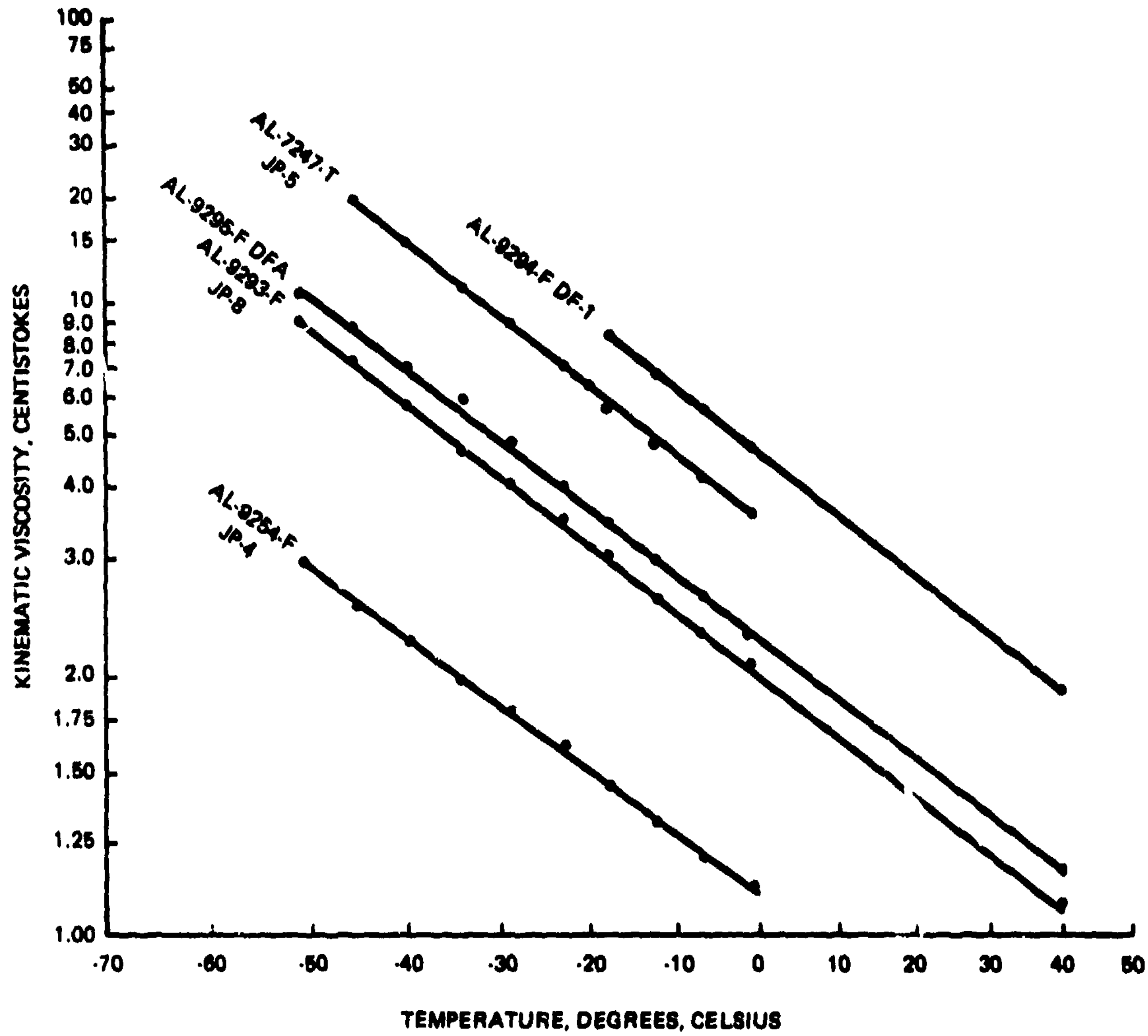

FIGURE 2. FUEL VISCOSITIES

TABLE 11. FSII REMAINING AFTER LOW-TEMPERATURE EXPOSURE TO 0.15 VOL% WATER

Sample, AL-	9254	9295	9295+FSII	9476*	9478*	9479*
Fuel Type	JP-4	DF-A	DF-A+FSII	JP-4	DF-A	JP-5
Initial FSII, vol%	0.10	NIL	0.11	0.07	0.28	0.09
FSII Remaining After Exposure to 0.15 vol% Water, at °C(°F)						
-12.2(10)	0.10	0.01	0.05	0.08	0.24	0.06
-17.8(0)	0.08	0.00	0.09	0.05	0.25	0.06
-23.3(-10)	0.09	0.01	0.10	0.06	0.28	0.06
-28.9(-20)	0.09	0.01	0.09	ND	ND	ND
-34.4(-30)	0.09	0.00	0.10	0.08	0.23	0.07
-40(-40)	0.09	0.00	0.11	ND	ND	ND
-45.6(-50)	0.09	0.00	0.10	ND	ND	ND
-51.1(-60)	0.09	0.00	0.10	0.06	0.22	0.05

* Alaska field sample.
ND = Not determined.

D. Contaminant Characterization at -51.1°C

A series of experiments were run at -51.1°C (-60°F) to determine contaminant characterization effects. Coarse AC test dust was added at 0.0, 0.01, and 0.10 wt% to the test fuel and dispersed using a combination of physical stirring and sonic treatment. The fuels used were JP-4 (AL-9254), DF-A (AL-9295), and DF-A + 0.15 vol% FSII (AL-9295 + FSII). The test samples were cooled slowly to -51.1°C (-60°F) and observed. The samples without dust remained clear while the dust-containing samples retained only a very slight amount of dispersed dust. In fact, most of the dust had settled out of the fuels prior to cooling. Photographs were attempted for documentation of the fuel and contaminant agglomeration at -51.1°C. Unfortunately, the fuels did not provide adequate contrast for satisfactory photographs.

E. Fuels Characterization Using Liquid-Solid Separator

Several of the test fuels were characterized using the liquid-solid separator (LSS). The LSS is a pressurized low-temperature filtration (0.22 micron) technique which determines the percent (vol or wt) of solid-crystal material at a given fuel temperature (7). Previous work had determined that when LSS solids exceed 3 vol%, plugging problems are encountered with vehicle fuel filters. The LSS results are shown in Table 12. The addition of 0.15 vol% FSII to DF-1 (AL-9294) and DF-A (AL-9295) did not appreciably affect low-temperature fuel behavior in the LSS. The addition of 100- to 300-ppm water to the fuels containing FSII also did not affect low-temperature LSS performance. A small amount of ice-like material was present on the LSS filters of water-containing fuels. Finally, the addition of 0.01 wt% AC Dust to the DF-A with FSII fuel did not affect LSS performance.

IV. CONCLUSIONS

The following conclusions are made based on the work performed during this project:

- Water and contaminants are closely monitored and removed from arctic turbine aircraft fuels.

- Arctic diesel fuels apparently do not receive special water and contaminant removal after delivery by the fuel supplier.

- The fuels examined had the typical petroleum temperature-viscosity relationship as evidenced by their linear plots on an ASTM temperature viscosity chart.

- Low-temperature fuel viscosities were not affected by the water contents in the range of 20 to 400 ppm.

- Fuel conductivities at varying low temperatures were generally constant (±2 CU) except for the JP-4 (Alaska), Jet A-1 Alaska, and DF-A (Alaska). These three fuels had conductivities which decreased with decreasing fuel temperature.

- Addition of 0.15 vol% FSII (EGME) to DF-1 and DF-A did not effect low-temperature viscosities or conductivities.

TABLE 12. LIQUID-SOLID SEPARATOR RESULTS

Fuel ID		Fuel Properties, °C				LSS
AL-	Type	Pour Point	Cloud Point	Freeze Point	Test Temp, °C	Solids, vol%
9294	DF-1	-36	-23	-18	-30	5
					-40	20
					-50	100
9294	DF-1 + 0.15 vol% FSII[a]				-30	6
					-40	17
9294	DF-1 + 0.15 vol% FSII + 0.03 vol% H_2O				-30	4
					-40	20
9295	DF-A	-56	-52	-52	-50	2
					-60	10
9295	DF-A + 0.15 vol% FSII				-50	4
9295	DF-A + 0.15 vol% FSII + 0.01 vol% H_2O				-50	2
9295	DF-A + 0.15 vol% FSII + 0.015 vol% H_2O				-50	3
9295	DF-A + 0.15 vol% FSII + 0.01 wt% AC Dust				-50	2
9478	DF-A (Alaska)	-53	-43	-47	-40	0
					-50	8
					-60	37
7247	JP-5	-57	-46	-46	-40	0
					-50	2
					-60	26
9479	JP-5 (Alaska)	-60	-52	-56	-50	1
					-60	4
9293	JP-8	-65	-55	-45	-60	1
9477	Jet A-1 (Alaska)	-58	-52	-49	-50	3
					-60	9

a = FSII = fuel system icing inhibitor = ethylene glycol monomethyl ether.

- Visible ice crystals were formed in fuels containing FSII when 100-ppm water was added.

- Fuels containing FSII were exposed to 0.15 vol% water at various low temperatures. The fuels retained their FSII contents.

- The test fuels would not hold a simulated contaminant. AC test dust was added to fuels at room temperature, and the fuels were cooled. Most of the dust settled out prior to cooling.

- A liquid-solid separator was used to characterize the test fuels at low temperatures. Addition of 0.15 vol% FSII did not affect fuel performance in the LSS.

V. RECOMMENDATIONS

The following recommendations for additional work are offered:

- Low-temperature properties should be determined for synthetic fuels derived from shale and coal.

- The effect of a proposed diesel fuel stabilization additive package on low-temperature fuel properties should be determined.

- Additional test procedures and experiments should be designed to better characterize FSII/water interactions at low temperatures.

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